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Biological Models Development: Mitosis and Meiosis

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Biological Models Development: Mitosis and Meiosis

A. Background and project objective

Previously, biological models for blind students (Franks & Murr, 1978) were developed to meet one of the pressing needs in the education of the visually handicapped--finding alternative methods of presenting material in biology that is usually exhibited visually. The development of the models for mitosis and meiosis generally followed procedures for legibility testing utilized in the previous project.

The principal objectives of the project were: (1) the development of mitosis and of meiosis models depicting the various phases of development during cell division, (2) the testing of symbols not previously used on models, and (3) the development of content components or units explaining what happens in each developmental phase of cell division. An equally important objective was the consideration of the materials for use as self-instructional reference materials by blind students. This objective involved informal exploration in developing a format for scripts for tape presentation to or use by blind students.

B. Supporting documentation

Development of the cell division was in response primarily to continuing requests from secondary science teachers in the field. A summary of supporting documentation is included in Appendix 1.

C. The APH Biological Models Description

The biological models in cell division consist of two sets of models or tactile schematics which are color cued for blind students with useful amounts of residual vision. A total of 6 mitosis and 13 meiosis models were developed. The models were molded of 15-mil, high impact styrene by a vacuum-forming process and averaged 9 inches (22.9 cm) in length on their longest sides. Maximum relief was approximately 1 inch (2.5 cm). Most of the symbols had been used on previous models and were found to be highly discriminable. Chromatic coding was employed to maximize the color and luminance contrasts previously found effective on other aids by low vision students.

D. Program development and evaluation

Development. Inspection of biology texts and reference materials was conducted to determine the model content--structures to be symbolized. Since the cell division sections of the various texts and reference materials were very brief, the actual sections were copied for review and inspection. Structures on seven (initial) mitosis models--corresponding to seven phases in miotic development--were identified. These were listed on a critique form and sent to six content experts in biological science for their comments. They were asked if critical structures were identified and if the structures represented were named correctly. They were asked for any additional comments they wished to make. They generally agreed on structure content and on terminology. Questions and comments related to disappearing membranes, (spindle) rays, and occurance of some events in phases. Structures tentatively suggested for display on each of the seven models are listed in Table 1.

TABLE 1

Critical Structures in Mitosis

Model #1: Interphase	Model #2: Prophase	Model #3: Metaphase	Model #4: Anaphase
1. Cell membrane	1. Cell membrane	1. Cell membrane	1. Cell membrane
2. Nuclear membrane	2. Nuclear membrane (dissolving)	2. Centriole	2. Centriole
3. Centriole	3. Centriole	3. Paired chromatids with centromere	3. Single chromatid with centromere
4. Chromosome	4. Paired chromatids with centromere	4. Protein fibers-astral rays	4. Protein fibers-astral rays
5. Nucleolus	5. Protein fibers-astral rays		

Model #5: Telophase	Model #6: Cytoplasmic Division	Model #7: New Interphase
1. Cell membrane	1. Cell membrane	1. Cell membrane
2. Nuclear membrane reappearing)	2. Nuclear membrane (reappearing)	2. Nuclear membrane
3. Centriole	3. Centriole	3. Centriole
4. Single chromatid with centromere	4. Chromosome	4. Chromosome
5. Nucleolus	5. Nucleolus	5. Nucleolus

A description of events for six stages of mitosis were identified from biology texts and reference materials. They are listed below.

ANIMAL MITOSIS

STAGE	DESCRIPTION
Prophase	1. Centrosome pair duplicates. a. Fibers develop and radiate out from the centrosomes to form the spindle. b. Centrosome pairs separate and move to opposite sides of the cell. 2. Nuclear membrane disappears. 3. Nucleolus disappears. 4. Double chromosomes appear.

ANIMAL MITOSIS (Cont.)

STAGE	DESCRIPTION
Metaphase	5. Chromosomes migrate to equatorial region of the cell. 6. Spindle fibers attach to the centromere of each chromosome.
Anaphase	7. Double chromosomes separate and become single chromosomes, each attached to spindle fibers at the centromere. a. A single chromosome from each of the formerly doubled chromosomes migrate to opposite side of the cell. (1) The single chromosomes appear to be pulled by the spindle fibers because the centromeres lead the way and the rest of the chromosomes trail along behind.
Telophase	8. Spindle fibers disappear. 9. Single chromosomes uncoil and disappear. 10. Nuclear membranes form around each group of daughter chromosomes. 11. Nucleolus develops inside each nucleus.
THE CELL MAY STOP AT THIS POINT AND BE A MULTINUCLEATE CELL, OR --	
Cytoplasmic Division	12. Opposite sides of the cell membrane begin to indent in the area of the equatorial plane. a. This indentation continues until the opposite sides of the cell membrane meet, thereby separating the cell into 2 daughter cells.
Interphase	13. Each daughter cell is complete and independent with 1 pair of centrosomes and a nucleus containing a nucleolus and long, uncoiled chromosomes which are not independently visible.

Following these outlines, 6 mitosis prototype models were developed and content units drafted. A content unit format was prepared for possible use as a script for recording content information for use by blind students using the models. Six educators of National status met at the National Science Teachers Association Convention in Washington, D. C., to review the mitosis models and to discuss related needs for blind biological science students. They also commented on the unit format and content. They were enthusiastic about the mitosis models but suggested that we consider:

1) Changes which will occur in biology textbooks as a result of new discoveries (e.g., two centromeres instead of one in prophase).
2) Effects of the expanding content in biology (e.g., more depth in content with increasing numbers of offerings in advanced high school biology) as well as simplified presentations (e.g., with meiosis especially) as biological content filters down in junior high (middle school) texts.
3) Inclusion of basic questions and answers related to uniquness of the medium and the content, reference and/or thought-stimulating questions possibly, and of relation to real life and purpose where possible.

The enthusiasm of these experts was revealed in their interest to follow-up, that is, to evaluate taped instructional programs if they were subsequently prepared.

When the prototypes and content units for mitotic cell division were revised, they were used as a model for meiosis. Thirteen prototype models were constructed, and content units were drafted which were based on the following outline constructed from the review of biological texts and reference materials.

Early Prophase I

Chromosomes become visible, the nucleolus and nuclear membrane disappear. Replication has occurred.

Middle Prophase I

Synapsis (pairing of homologous chromosomes).

Late Prophase I

Separation of identical chromatids everywhere except at their centromeres.

Metaphase I

Equatorial alignment of the centromeres of the chromosomes.

Anaphase I

Separation and migration of the homologous chromosomes to opposite poles of the cell. Chromatids remain joined by their centromeres.

Telophase I

Cell division producing two cells, each containing a nucleus with chromosomes that are homologous with the other cell.
Note: The chromosomal contents of these two cells are NOT identical.

Second Meiotic Division

Prophase II

Disappearance of the nuclear membranes and formation of the spindles begin.

Metaphase II

Equatorial alignment of the centromeres of the chromosomes.

Anaphase II

Separation and migration of the chromatids to opposite poles of the cells.

Telophase II

Cell division to produce four cells, each having a haploid nucleus.

Evaluation. Six prototypes were designed and constructed to portray the events occuring in mitosis and 13 for meiosis. Symbols were identified for use on the models. Symbols varying from those previously evaluated were tested for legibility. Pseudo-models and materials were constructed for use in testing the legibility of the symbols. The major differences in symbols from those used on other biological models were in size. Several of the symbols had larger areas and some of the meiosis symbols were smaller than those previously used.

Students generally were used who were in or had completed biology or a related science course. To insure that the tasks were performed tactually, students with useful residual vision used shades as in previous legibility tests of biological symbols. A total of 24 students were included in the mitosis evaluation. A breakdown of students by age and grade range and by sex is presented in Table 2.

TABLE 2

Mitosis Symbols

N	Age Range	Mean Age	Grade Range	% Female	% Male
24	14-21	17	9-12	37.5	62.5

A total of 11 students were included in the meiosis evaluation. A breakdown of students by age and grade range and by sex is presented in Table 3.

TABLE 3

Meiosis Symbols

N	Age Range	Mean Age	Grade Range	% Female	% Male
11	15-21	17.3	9-12	63.6	36.4

Overall performance on the two tests approached 100% correct performance, with only one incorrect response on one mitosis symbol. A breakdown for legibility by symbol for mitosis (N=24) and meiosis (N=11) is presented in Table 4.

TABLE 4

Symbol Legibility--Mitosis and Meiosis

N	Symbol	Percent Correct
24	Cell Membrane	95.83
24	Centriole	100.00
24	Nuclear Membrane	100.00
24	Chromosome	100.00
24	Nucleus	100.00
24	Chromatid	100.00
24	Nuclear Membrane--Dissolving	100.00

TABLE 4 (Cont.)

N	Symbol	Percent Correct
24	Paired Chromatids	100.00
24	Protein Fibers/Astral Rays	100.00
11	Revised Centriole	100.00
11	Metaphase I, Chromosome A	100.00
11	Metaphase II, Chromosome B	100.00
11	Homologous Chromosomes, Diplotene Stage	100.00
11	Chromosomes, Z-P Stages	100.00
11	Telophase II, Chromosome A	100.00
11	Telophase II, Chromosome B	100.00
11	Telophase II, Chromosome C	100.00
11	Telophase II, Chromosome D	100.00

A breakdown by student for number of correct symbols is included in Appendix

APPENDIX 1

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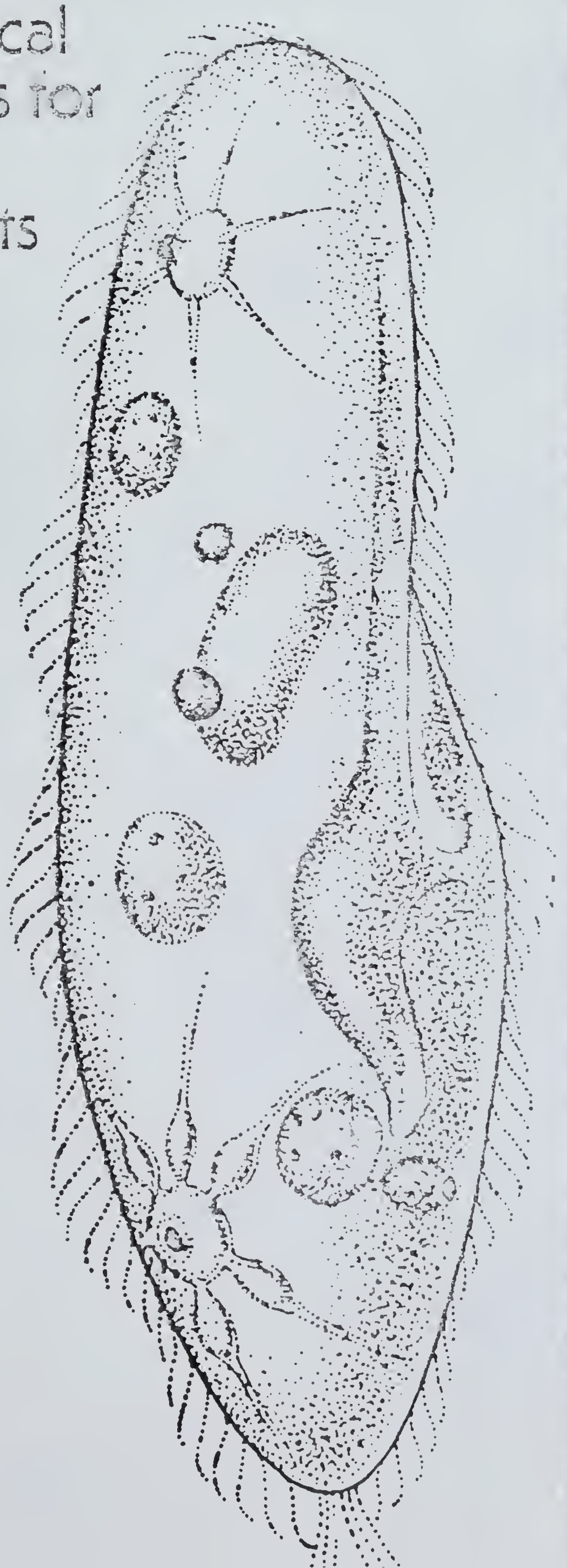
Biological Models for Blind Students



Biological Models for Blind Students

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Dr. Franks is a research scientist in the Department of Educational Research at the American Printing House for the Blind, Inc. Mr. Murr was a research assistant at APH at the time of this study.

Abstract: *In response to an expressed need for inexpensive biological models for blind students, the American Printing House for the Blind has developed a set of 19 plastic models (schematics) which illustrate representative species of the major invertebrate phyla and component structures of flowering plants. The biological features depicted on the models were found to be highly discriminable in a test of legibility (95 percent overall correct responses) with 42 legally blind students (grades 7-12). The models emphasize simplicity, but offer additional cues where complexity occurs. Texture, size, shape, and relief were used for maximum legibility. Chromatic color coding was employed to maximize color and luminance contrasts for low vision students. The models averaged nine inches (22.9 cm) in length on their longest sides.*

Note: *The research reported herein was performed pursuant to Contract No. 300-75-0046 for the Special Office for the Visually Impaired with the Bureau of Education for the Handicapped: U.S. Office of Education; Department of Health, Education, and Welfare.*

One of the most pressing needs in the education of the visually handicapped is finding alternate methods of presenting material that is usually exhibited visually. The sighted biology student relies upon a number of nonverbal visual learning aids to attain curriculum objectives. Textbook pictures, diagrams, and illustrations, along with three-dimensional models and laboratory specimens make a major contribution to the learning process. However, most of these aids are of little or no value to the visually handicapped student. Alternate methods of presentation must be found if these students are to obtain the valuable, and perhaps unique, information normally imparted through these media.

The need for instructional materials in the biological sciences was emphasized by participants in the Institute on Instructional Materials Development in Science for Visually Handicapped (Franks, 1970), held at the American Printing House for the Blind (APH). Participants agreed that the biological sciences were an area with a critical shortage of educational materials. In particular, they cited the lack of satisfactory tactile models of representative species of the major plant and invertebrate animal phyla.

Biological models currently available include enlarged, commercially produced, three-dimensional wooden or plastic models and embossed representations which appear in braille textbooks. The three-dimensional models are typically designed for visual representation, frequently lack adequate tactual legibility, and are usually quite expensive. Similarly, embossed diagrams are often illegible due to the inherent limitations of two-dimensional representations of three-dimensional objects and the addition of confusing indicator lines and dots. These indicator lines are easily confused with the outline of the model itself, and, often, the result is a meaningless maze of raised lines and braille dots.

Merry and Merry (1933) reported a study exploring the ease with which blind children in kindergarten through grade six recognized simple two- and three-dimensional designs and pictures embossed in paper. They found that the recognition ability of these children was very limited, with 16 percent of the subjects failing to identify any of the pictures. Despite this finding, embossed diagrams and pictures continued to be produced (Heisler, 1959).

Mandola (1967) has pointed out that one of the most common errors made in developing tactile aids is assuming that what is seen and understood by the sighted will be similarly understood by the visually handicapped through graphic aids. Adequate tactile aids must not only replace visual symbols with tactile symbols, but in doing so must meet the criteria necessary for accurate tactual perception (Franks, 1971). Recently, a series of three-dimensional tactile maps (landforms), with chromatic colored illustrations of basic geographical concepts, were developed at APH (Franks & Baird, 1971a). They were molded of high-impact styrene by a vacuum-forming process and have proven to be very effective teaching aids (Franks & Baird, 1971b).

Vacuum-formed plastic is a low-cost medium which appears to offer a significant improvement over embossed diagrams. It is quite tractable and lends itself well to the

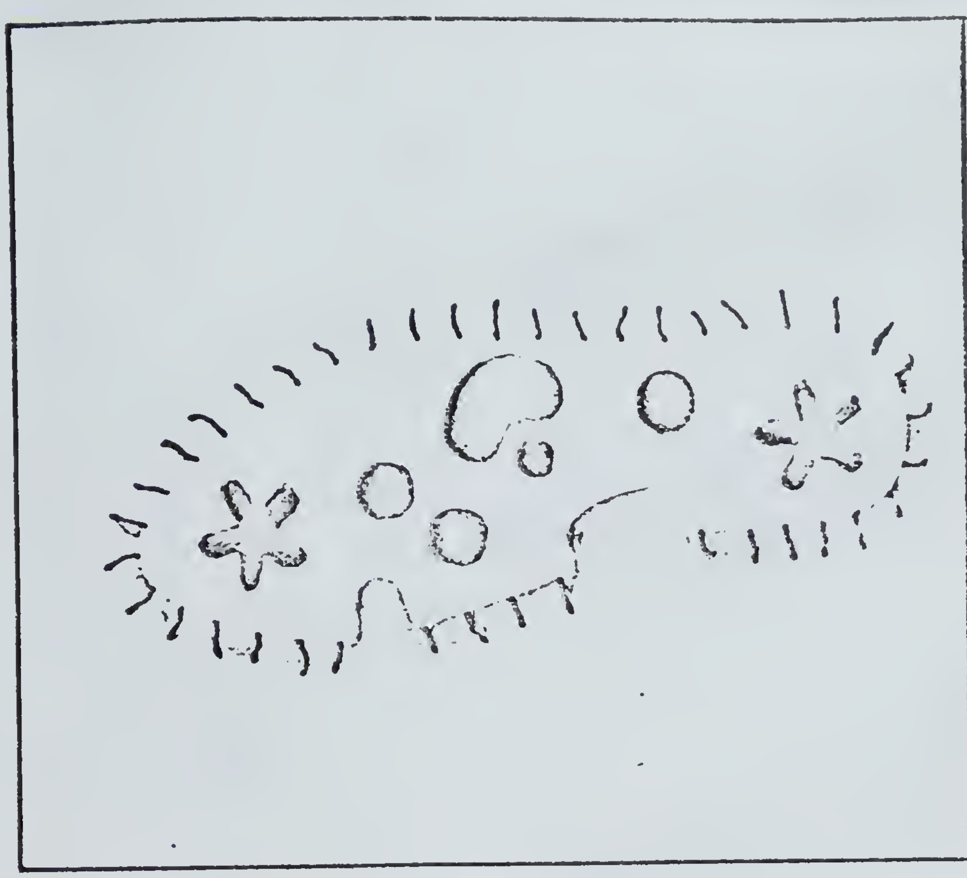

Figure 1. Paramecium

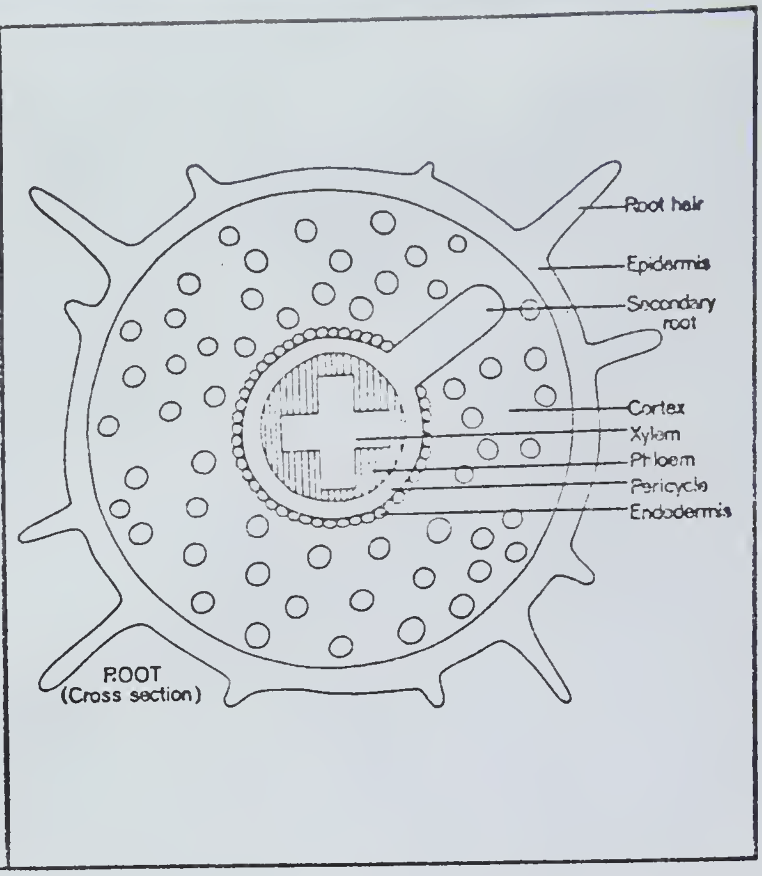

Figure 2. Root (cross section)

representation of depth, texture, contour, shape, and size. Component recognition is increased by the combination of tactual cues and the addition of color coding. The APH Science Institute (Franks, 1970) recognized the inherent qualities of vacuum-formed plastic and recommended that it be used in the construction of more adequate biological models for visually handicapped students.

The purpose of this study was to apply this technique to the biological sciences to provide materials which afford greater tactile legibility than existing embossed diagrams and three-dimensional aids. Specifically, a set of 19 vacuum-formed biological models (schematics) were tested for tactual legibility.

Subjects

A total of 24 male and 18 female braille readers enrolled in summer school programs at the Ohio State School for the Blind, the Missouri School for the Blind, and the New York State School for the Blind, participated in this study. All students had been enrolled in academic programs during the previous school year in grades 7-12. Thirteen of these students attended public schools during the regular school year.

Materials

The APH Science Institute suggested that models be developed to illustrate the most representative species of each invertebrate animal and plant phylum. According to the *Modern Classification of Organisms* (Otto & Towle, 1965), there are 18 such animal phyla and 2 plant phyla. However, a visual inspection of four series of junior and senior high school biology textbooks, two series of science books for the elementary grades, and several college zoology texts, revealed that only 8 of the 18 invertebrate phyla received sufficient illustrative and textual treatment to warrant development of models. Similarly, an analysis of biology texts (Murr, 1971) showed that a single class (flowering plants) within the plant kingdom was afforded almost as much consideration as all the other plant classes combined. Development of models, therefore, was restricted to the most representative species of the major invertebrate phyla and to the sections of flowering plants.

The specific invertebrate species chosen to represent each phyla were the ones that had been identified as representative of their respective phyla and enjoyed the widest use in science courses at all grade levels. The flowering plant illustrations chosen for modeling depicted plant structures that appeared commonly in a majority of the biology texts analyzed.

Table 1 lists the models that were developed. It was necessary to construct more than one model of some animals in order to display the essential structures and still maintain adequate tactual legibility. Figure 1 is an example of one of the 19 models, the paramecium.

The choice of which structures to include in each model was determined by a visual inspection of illustrations in textbooks. Important structures are usually labeled and directly referenced in the text. If a plant structure was so indicated in both of the biology texts published by APH or in a majority of the four series of textbooks analyzed (Murr, 1971), then the structure was depicted in the models. Animal structures included were determined by their common appearance in comparable textbook illustrations. As many important structures as could be legibly presented in a model were included.

The models were constructed with an emphasis on simplicity and offered additional cues only where comlexity made them unavoidable. Texture, size, shape, and relief were used to provide maximum legibility. Structures were designed to be as realistic as possible yet simple enough to permit efficient tactual identification. An attempt was made to keep model size as small as possible to permit tactual integration but large enough to maintain legibility, and the relative proportion and position of parts. Tactile coding of the models was consistent with findings from studies in tactual research (Nolan & Morris, 1971; Wiedel & Groves, 1969) where possible.

The models were molded of 15-mil, high-impact styrene by a vacuum-forming process and averaged 9 inches (22.9 cm) in length on their longest sides. Maximum relief was approximately 1 inch (2.5 cm). Many of the areal symbols used on the models previously had been found to be highly discriminable (Morris & Nolan, 1961). The models were painted with acrylic lacquer. Chromatic coding was employed to maximize the color and luminance contrasts previously found effective on other aids for use by low-vision students (Franks & Baird, 1971a, 1971b).

For testing purposes, 19 sets of 3.5 inch (8.8 cm) square plastic cue cards were developed to display individual parts of each model. Some of the cards contained intact model parts as they appeared on the models. However, many model parts extended over large portions of the model and could not be entirely exhibited on the cue cards. In these cases, a sample of the areal (1.4 inch [3.5 cm] squares) or linear (small section) symbol composing the model part was displayed on the cue card.

Table 1. Zoological and Botanical Illustrations Selected for Modeling

Model	View
Animal	
Paramecium	Sagittal section
Sponge	Sagittal section
Hydra	Sagittal section
Planarian (3)	External views (dorsal and ventral) Sagittal sections (nervous system, digestive system) Transverse section
Clam	Sagittal section
Earthworm (2)	Sagittal section Transverse section
Starfish	Sagittal section
Grasshopper (2)	Sagittal sections (respiratory system, digestive system)
Plant	
Leaf	Transverse section
Root	Transverse section
Woody stem	Transverse section
Root tip	Sagittal section
Flower	Sagittal section
Seed	Sagittal section
Lower leaf epidermis	Sagittal section

A number of short verbal directions were developed to accompany the presentation of the different types of cue cards. The first sentence of each direction was the same: "Here is a cue card." The second, and usually last, sentence directed the subject to locate a point, "Find this structure on the model."; areal, "Show me a texture like this on the model."; or linear, "Show me a part of the model which is like the sample on the cue card."

Procedure

Pilot testing revealed that it would be difficult to test all 19 biological models with one subject in a single test session. It was decided, therefore, to divide the models into sets of 9 and 10 models each. The composition of these final testing sets represented an effort to segregate the models with comparable physical configurations and pilot test times into two groups of relatively equivalent content and difficulty.

The two sets of biological models were tested by assigning them to successive subjects of a grade level in a counterbalanced order. The order of model presentation was randomly determined prior to field test administration and cue cards were shuffled after presentation of each model.

The testing session was conducted with the experimenter reading to the subject (who was blindfolded if he had useful vision) a set of standard instructions describing the purpose of the study, the procedure to be followed, and the three kinds of cue cards that would be used. The first model was then presented to the subject for a preliminary inspection. This familiarization period with the model continued until the subject was "ready to begin" or one minute had elapsed. Subsequently, the experimenter presented the first cue card to the subject and read the appropriate verbal direction from the testing sheet. The subject was allowed as much time as he desired to identify the part on the model corresponding to the part displayed on the cue card. After the subject had located what he believed was the same model part, he touched it with his finger and said, "Here." The experimenter recorded the accuracy of his response. As soon as the subject had made a response to one cue card, another was presented until all the cards for a particular model were exhausted. A similar procedure was followed in the presentation of the eight or nine remaining models in the group. Before the second and third model presentations, the explanation of the three kinds of cue cards was reread to the subject, but thereafter only upon his request.

Results

One hundred and two parts on 19 models were evaluated for their tactual discriminability. The mean percentage of correct subject responses was 95 percent. A criterion of 85 percent correct responses-per-model part was set prior to testing. Ninety-four of the tested parts exceeded the criterion, while the remaining eight parts were correctly located by 62 to 81 percent of the subjects. The eight failing symbols were parts of five models.

> ". . . each of these parts are realistic symbols which convey more information about these structures than an unrelated abstract symbol would reveal."

Discussion

The high level of student performance attests to the overall highly discriminable quality of the models. The eight model parts which failed to meet the criterion were examined in their total context to determine the cause of their failure. Each part was studied with respect to its tactile quality, proximity, and similarity to other component parts, cue card and test question employed, and prior general instructions. The results of this informal analysis were used to make modifications to the models. Wherever a modification to a model part appeared insufficient to correct a deficiency, it was entirely replaced by another model part or symbol shown to be discriminable in this study.

Modifications were made to three of the five defective models by replacing one illegible symbol with another proven discriminable in this study. However, the changes made to the two remaining models included both multiple substitution of discriminable for indiscriminable symbols, and the modification of two body openings per model. "Opening" symbols constituted just five percent of all parts tested, but accounted for approximately 40 percent of the model parts below criterion. The disproportionate number of these symbols in the failure group raised serious doubts about the tactile quality of any new "opening" symbol used to replace an inadequate one. With these considerations in mind, an APH project review committee recommended the retesting of these latter two models to insure their tactile adequacy.

Twenty-two braille readers enrolled in academic classes at the Kentucky School for the Blind from grades 9-12 were used to retest the modified models. The procedure used to test the models was identical to the testing format followed in the main study. Appropriate additions and deletions were made to the sets of cue cards in accordance with modifications made to the models.

Every symbol which failed its first test of tactual discriminability and was modified or replaced prior to retest was found to be discriminable. The mean percentage of correct responses made by the 22 subjects was identical with the performance of subjects in the main study (95 percent). Fourteen of 15 model parts tested exceeded the test criterion of 85 percent correct responses per part.

The mouth opening on the starfish model was not tested in the principal study but was modified and tested in the retest of the starfish model. Despite the modification of the mouth opening, this model part failed to meet the test criterion in a test of legibility. The opening was located by 16 of 22 students (73 percent), and therefore, was not discriminable by the standards set for this study.

The failure of the mouth symbol was apparently caused by its similarity to the openings formed between the tube feet and body wall. Modification or replacement of the mouth opening or tube feet symbols was undesirable since each of these parts are realistic symbols which convey more information about these structures than an unrelated abstract symbol would reveal. It is suggested that the teacher note this difficulty and instruct students to identify the mouth by its location and in relation to other relevant body parts (such as its location on the opposite end of the model away from the tube feet; its proximity to the stomach).

Summary

Nineteen biological models were developed and the critical features on each model tested for legibility. A 95 percent correct response, overall, was achieved by 42 legally blind students. Features not meeting the criterion for discriminability (85 percent correct responses) were modified or replaced and retested on 22 legally blind students. The criterion of discriminability (85%) was reached on all but the mouth opening on one model (starfish). This set of biological models is available from the American Printing House for the Blind (Catalog number 1-0301). ■

References

Franks, F. L. *Instructional materials development in science for visually handicapped.* Unpublished Institute Report, American Printing House for the Blind, 1970.

Franks, F. L. *An operational approach to the development of tangible apparatus in mathematics and science.* Unpublished report, American Printing House for the Blind, 1971.

Franks, F. L., & Baird, R. M. Tactual and chromatic discrimination of geographical concepts as illustrated on landforms. *Exceptional Children,* 1971a, 38, 321-324.

Franks, F. L., & Baird, R. M. *Teaching geographical concepts to young visually handicapped students.* Unpublished study, American Printing House for the Blind, 1971b.

Heisler, W. T. *Manual of biology diagrams.* Louisville, Ky.: American Printing House, 1959.

Mandola, J. *Graphic aids for the blind.* Unpublished master's thesis, Michigan State University, 1967.

Merry, R., & Merry, F. Tactual recognition of embossed pictures by blind children. *Journal of Applied Psychology,* 1933, 17, 148-163.

Morris, J., & Nolan, C. Discriminability of tactual patterns. *International Journal for the Education of the Blind,* 1961, 11, 50-54.

Murr, M. J. *Seed plant illustrations in biology textbooks.* Unpublished report, American Printing House for the Blind, 1971.

Nolan, C. Y., & Morris, J. E. *Improvement of tactual symbols for blind children: Final report* (Project No. 5-0421; Grant No. OEG-32-27-0000-1012). Louisville, Ky.: American Printing House for the Blind, 1971. (ERIC Document Reproduction Service No. ED 070 228)

Otto, J. H., & Towle, A. *Modern biology.* New York: Holt, Rinehart & Winston, 1965.

Wiedel, J. W., & Groves, P. A. *Tactual mapping: Design, reproduction, reading and interpretation: Final report* (SRS Grant No. RD-2557-S). College Park, Md.: University of Maryland (Department of Geography), 1969.

APPENDIX 2

MITOSIS

BIOLOGICAL MODELS

STUDENT DATA

	Age	Sex	Grade	Extent of Science Instruction	Academic or Non-academic	Number Correct/ Number Symbols
1.	16	M	10	Biology	A	9/9
2.	14	M	10	Biology	A	9/9
3.	15	F	10	Biology	NA	9/9
4.	18	M	12	Biology	A	9/9
5.	16	F	10	Biology	A	9/9
6.	19	M	11	Biology	A	9/9
7.	19	M	10	Biology	NA	9/9
8.	19	F	11	Biology	NA	9/9
9.	17	F	10	Biology	NA	9/9
10.	15	F	10	Biology	NA	9/9
11.	17	F	10	Biology	NA	9/9
12.	20	M	11		A	9/9
13.	21	M	12		A	9/9
14.	18	M	11		A	9/9
15.	16	M	10		A	9/9
16.	15	M	10		A	9/9
17.	16	F	10		A	8/9
18.	15	F	9	9th Grade Science	A	9/9
19.	19	M	12	Biology	A	9/9
20.	18	M	12	9th Grade Science	A	9/9
21.	17	M	11	General Science	A	9/9
22.	17	M	11	Biology	A	9/9
23.	15	M	10	Biology	A	9/9
24.	16	F	11	9th Grade Science	A	9/9

MEIOSIS

BIOLOGICAL MODELS

STUDENT DATA

	Age	Sex	Grade	Extent of Science Instruction	Academic or Non-academic	Number Correct/ Number Symbols
1.	18	F	12	Biology	A	10/10
2.	21	F	12	Biology	A	10/10
3.	16	M	10	Physical & Earth Sci.	A	10/10
4.	15	F	10	Earth & Space Sci.	A	10/10
5.	17	M	9	Physical & Earth Sci.	A	10/10
6.	18	F	12	Biology	A	10/10
7.	17	F	12	Earth & Space Sci.	A	10/10
8.	18	M	11	Biology	A	10/10
9.	19	M	10	Earth & Space Sci.	A	10/10
10.	16	F	10	Earth & Space Sci.	A	10/10
11.	15	F	9	Physical & Earth Sci.	A	10/10